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ORIGINAL PAPER

# National assessment of the fragmentation, accessibility and anthropogenic pressure on the forests in Mexico

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**Abstract**: Forest managers and policy makers increasingly demand to have access to estimates of forest fragmentation, human accessibility to forest areas and levels of anthropogenic pressure on the remaining forests to integrate them into monitoring systems, management and conservation plans. Forest fragmentation is defined as the breaking up of a forest unit, where the number of patches and the amount of expose edge increase while the amount of core area decreases. Forest fragmentation studies in Mexico have been limited to local or regional levels and have concentrated only on specific forest types. This paper presents an assessment of the fragmentation of all forest types at the national level, their effective proximity to anthropogenic influences, and the development of an indicator of anthropogenic pressure on the forests areas. Broadleaf forests, tropical evergreen forests and tropical dry deciduous forests show the greatest fragmentation. Almost half (47%) of the tropical forests are in close effective proximity to anthropogenic influences and only 12% of their area can be considered isolated from anthropogenic influences. The values for the temperate forests are 23% and 29% respectively. Anthropogenic pressure in the immediate vicinity of anthropogenic activities is much higher in the tropical forests (75 in a scale 0-100) than in the temperate forests (30). When considering these results jointly, the tropical forests, and more specifically, the tropical evergreen forests and tropical dry deciduous forests are under the greatest pressure and risks of degradation.

**Keywords**: forest fragmentation; effective proximity; anthropogenic pressure; Mexico forests; GIS.

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## Introduction

Historically, emphasis has been placed on evaluating the extent of the forest cover and deforestation rates (e.g. Achard et al. 2002; FAO Global Forest Resources Assessments http://www.fao.org/forestry/1191/en/). Although this information is important for assessing the sustainability of forest ecosystems, equally important are the conditions of the remaining forests with regard to their ownership, composition, structure, spatial pattern, and spatial relation to anthropogenic influences (here defined as population centres, roads and anthropogenic land uses). The characterization of the spatial pattern (estimated through different measures of fragmentation) is of particular importance to better assess the full effects of forest loss and ecosystem fragmentation and their effects in the capacity of the remaining forests to sustain critical ecosystem components and functions at different temporal and spatial scales (Murcia 1995; Baskent & Jordan 1996; Herzog et al. 2001; Lindenmayer et al. 2002; McAlpine & Eyre 2002; Garcia-Rigoro & Saura 2005; Kupfer 2006).

The topic of forest, and more generally, habitat fragmentation is complex and it has been extensively studied (Fazey et al. 2005; Lindenmayer & Fisher 2006). Two important points emerge from this body of literature. First, there is ambiguity on what "fragmentation" is and what its effects are (Villard 2002; Groom et al. 2005; Lindenmayer & Fisher 2006). The factors that contribute to making the concept of habitat fragmentation vague and

context dependent are presented and discussed by Lord & Norton (1990), Harrison & Bruna (1999), Haila (2002), McGarigal & Cushman (2002), Villard (2002), Groom et al. (2005) and Lindenmayer & Fisher (2006). Second, although it is not easy to draw broad general conclusions regarding forest fragmentation and its effects, there is general agreement among scientists and forest managers about the need to quantify it and to integrate it into management and conservation plans as well as simulations that will assist us in better understanding the interactions among human activities, forest features, and ecological processes (Hargis et al. 1998; Debinski & Holt 2000; Santiago & Martinez-Millan 2001; Boutin & Herbert 2002; McGarigal & Cushman 2002; Ritters et al. 2002; Rutledge 2003; Kupfer 2006). In this study, forest fragmentation is defined as the breaking up of a forest unit, where the number of patches and the amount of expose edge increase while the amount of core area decreases (Meddens et al. 2008). Core area is defined as a forest area free of edge effects.

Some studies have estimated the level of fragmentation of the temperate and tropical forests at the global (e.g. Riitters et al. 2000; Wade et al. 2003) and national levels (e.g. Heilman et al. 2002; Riitters et al. 2004; Kupfer 2006). More common are studies that concentrate on the impacts of forest fragmentation on specific flora and fauna at local or regional levels (e.g. Schmiegelow & Mönkkönen 2002; Zipkin et al. 2009). This last trend is the case for the approximately 41 studies published in the last 10 years on the fragmentation of the forests in Mexico. For example, they have concentrated on the effects of forests fragmentation on primates (Estrada & Coates-Estrada 1996), specific plant species (Ochoa-Gaona et al. 2004; Herrerias-Diego et al. 2006; Arroyo-Rodriguez et al. 2009), or the characterization of fragmentation patterns of specific forest types over relative small study areas (Cayuela et al. 2006; Galicia et al. 2008). When studies have been conducted in Mexico at the national level, they have concentrated only on specific forest types (e.g. Trejo & Dirzo 2000). All these studies have not used a common methodology which complicates comparisons of results and integration of information at multiple scales. Only recently has there been a national assessment of the fragmentation of all the forest types in Mexico (Moreno-Sanchez et al. 2011). This study reports numerical fragmentation metrics calculated using FragStats 3.3. (McGarigal et al. 2002). Although the data provided is valuable, there is to date no spatially explicit representation of the fragmentation levels of all the forest types existing in the country. This information is fundamental to support management and conservation decisions, as well as the study of the spatial relations of forest fragmentation with other natural and anthropogenic features and processes.

The effective proximity of the remaining forests to anthropogenic influences and the associated anthropogenic pressure is also important information to evaluate the sustainability of these ecosystems (Nelson & Hellerstein 1997; Verburg et al. 2004; Zhang et al. 2005; Frair et al. 2008). The specific effects of proximity to population centres, roads, and anthropogenic activities on the forests vary in different social, economic, and ecological contexts (e.g. Agrawal 1995; Chomitz & Gray 1996; Barlow et al. 1998; Heilman et al. 2002; Alix-Garcia et al. 2004; Carr et al. 2005; Blackman et al. 2008; Meddens et al. 2008; Bhusal et al. 2009). However, regardless of the context forests near population centres face a special set of challenges that will only intensify as these communities grow in area, population, and complexity (Nowak et al. 2005). For example, research and empirical evidence find that improved access to forest areas and proximity to anthropogenic activities influence deforestation rates (Chomitz & Gray 1996; Nepstad et al. 2001; Soares-Filho et al. 2001; Munroe et al. 2002; Verburg et al. 2004; Cayuela et al. 2006). In Mexico, analytical and empirical evidence shows that, generally, forests closer to population centres and anthropogenic activities are subject to greater pressures and disturbances such as fires, overexploitation, or deforestation (Nelson & Hellerstein 1997; Román-Cuesta et al. 2004; Works & Hadley 2004; Cayuela et al. 2006). Estimates of deforestation in Mexico vary from 365,000 to 1.5 million hectares (ha) per year (Mas et al. 2004). Recent land use change studies place the rates of deforestation in the period 1976–2000 at 0.25% per year for temperate forests and 0.76% per year for tropical forests (Mas et al. 2004; Velazquez et al. 2005). To date in Mexico there is no national level estimation of the effective proximity of the forests to anthropogenic influences and the associated anthropogenic pressure on them.

The static nature of printed maps reporting results of forest fragmentation studies made them of limited use to support forest management and conservation decisions at the strategic and tactical levels. This is particularly true when those maps cover very large areas. If these maps are made available in digital form, they should be easily accessible by a broad audience of concern citizens, forest managers, and policy makers with different levels of access to computer technology and geographic information systems know-how.

The aims of this study were to: (1) Generate a spatially explicit national evaluation of the fragmentation all types of temperate and tropical forests existing in Mexico; (2) assess the effective proximity of all forests types to anthropogenic activities; (3) generate an estimate of the level of anthropogenic pressure on the remaining forest areas based on the location of deforested areas; and (4) provide broad and user-friendly access to maps of these results through the use of Google Earth™ on the World Wide Web (WWW or the Web).

## Methods

### Data sets

The National Institute of Statistics, Geography, and Informatics (INEGI) Land Use and Vegetation Cover vector data sets scale 1:250,000 known as Series II (from 1993), and Series III (from 2002) (see INEGI 2005) were used to identify the extent of two types of temperate forests: coniferous forests (dominated by numerous species of pine tress *Pinus* spp.) and broadleaf forests (dominated by oaks *Quercus* spp. usually in complex mixes with pines); and three types of tropical forests: tropical dry deciduous forests, tropical sub-evergreen forests, and tropical evergreen

forests. These forests are composed of complex mixes of tropical trees species, and they differ from each other on the average height of the trees and on the length of the season that the trees maintain their foliage (which is mostly determined by the amount and distribution of precipitation throughout the year). Appendix 1 presents the vegetation covers from the Series II and III included in each forest type here defined. INEGI has revised and made compatible the vegetation cover information from the Series II and Series III (FAO 2010). These land cover maps were also used to identify anthropogenic land uses for 1993 and 2002 (Appendix 2). Only the land uses with the highest certainty of being of anthropogenic in nature were included in this class. For reference, Fig. 1 shows the geographical extent of the temperate forests according to the Series III (2002). These forests are usually found in the medium to high elevations of the sierras that crisscross the country. Fig. 2 shows the extent of the tropical forests for the same date. These forests are found in the coastal areas and low elevations throughout the country. Due to their complexity and level of detail, the distribution of the more specific forest types defined in this study, and the location of the population centers in and around the forest areas are better explored in the Google Earth™ application developed as part of this study (http://fast.ucdenver.edu/Mexico).

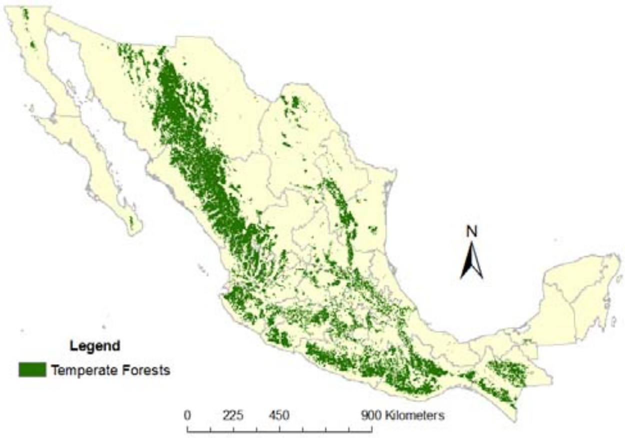


**Fig. 1 Location of the temperate forests according to the INEGI Series III from 2002.**

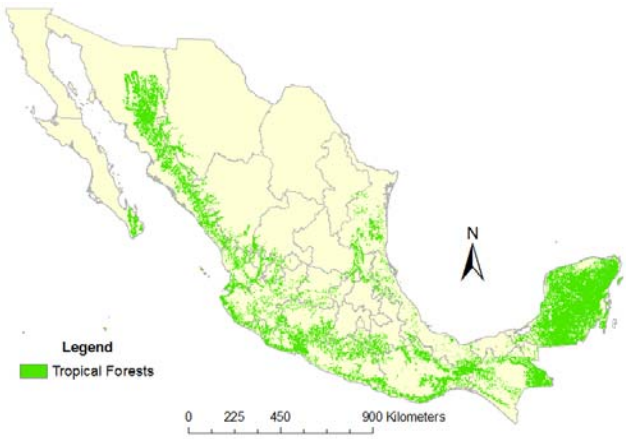


**Fig. 2 Location of the tropical forests according to the INEGI Series III from 2002.**

The INEGI's Digital Elevation Model from 2003 (http://mapserver.inegi.org.mx/DescargaMDEWeb/?s=geo&c=977) with a resolution of 1 × 1 seconds of degree of latitude/longitude (i.e. approximately 90 m per cell side) was resampled to a cell size of 100 × 100 m and this was used to derive slope information. The population centre locations (approximately 200,000 of them) were obtained from the 2005 INEGI population census (http://www.e-mex-ico.gob.mx/wb2/eMex/eMex_INEGI__XII_Censo_general_de_poblacion_y_vivie).

The latest information on the location of roads at the national level (corresponding to the year 2007) was obtained from the Mexican Institute of Transportation (Instituto Mexicano del Transporte IMT http://www.imt.mx/). Unpaved roads are not part of this data set, this information is not currently available in digital form for the country, and it is not likely that it will become available in the short run. For the purposes and scale of our study, and through the methods we used, the location of anthropogenic land uses and the detailed information on the location of even very small population centres in the forest areas provide some degree of alleviation for the absence of this information as we will present in the discussion section.

The coastal islands of Mexico were not included in this study. All the data sets were obtained as ESRI (Environmental Systems Research Institute, Redlands California) shapefiles or grid (raster) files. All of them were re-projected to the Lambert Conformal Conic datum NAD 83 units meters coordinate system for analysis. The study results were converted to latitude/longitude WGS 84 geographical coordinates in decimal degrees for display in Google Earth™.

## Assessment of forest fragmentation

The level of fragmentation of the forests was estimated using the moving window method proposed by Riitters et al. (2000). This method belongs to a group of moving-window fragmentation indices (Kupfer 2006). The moving window defines a neighborhood that is analyzed to estimate the fragmentation value of the centre cell in the window. Fragmentation classes are assigned to the centre cell based on the proportion and adjacency of forested and non-forested cells that fall in the analysis window (Riitters et al. 2000). The fragmentation classes are defined by a combination of two values (Riitters et al. 2000): $P_f$ and $P_{ff}$. $P_f$ is the proportion of pixels in the analysis window that are forested. $P_{ff}$ is defined as the proportion of all adjacent (cardinal directions only) pixel pairs that include at least one forest pixel, for which both pixels are forested. $P_{ff}$ estimates the conditional probability that, given a pixel of forest, its neighbor is also forest. Given this, each fragmentation class is identified by the following $P_f$ and $P_{ff}$ value combinations: (1) Interior, for which $P_f = 1.0$; (2) perforated, $P_f > 0.6$ and $P_f - P_{ff} > 0$; (3) edge, $P_f > 0.6$ and $P_f - P_{ff} < 0$; (4) transitional, $0.4 < P_f < 0.6$; and (5) patch, $P_f < 0.4$. For justification of why this method was chosen for our study see Appendix 3.

The fragmentation analysis was applied to each forest type

here defined at the national level (Appendix 1). The vegetation covers included in each forest type were extracted (and later merged) from the INEGI's Series III land cover data provided in ESRI's shapefile format. Then each forest type extent was converted to grids with a cell size of 100 × 100 m using ArcGIS 9.3 (ESRI, Redlands California). The justification for the choice of this cell size is given in Appendix 4.

To provide a broad basis of mapped fragmentation information the fragmentation model was run for each forest type at three different analysis window sizes: 3×3, 5×5, and 9×9 cells. In a 3×3 cells analysis window, the fragmentation value of the centre cell is influenced by the cells found in a neighborhood of 100 m. The fragmentation results using this window size can be used under "optimistic" scenarios where the forest fragmentation is considered to have limited impacts, and its positive or negative effects do not penetrate deeply into the forest patches. The size of this neighborhood radius increases to 200 m in the 5×5 analysis window size. The fragmentation results using this window size can be used under "moderate" scenarios where fragmentation is considered to have greater impacts and its effects to penetrate deeper into the forest patches. Finally, in the 9×9 window, the neighborhood increases to 400 m in radius. The fragmentation results using this window size can be used under "conservative" scenarios where the impacts of forest fragmentation are considered to be extensive and its effects penetrate deeply into the forest patches. In terms of penetration of effects found at the edge of the forest, the distance of a forest centre cell to the nearest non-forest cell in the 3×3, 5×5, and 9×9 analysis window sizes is 200, 300, and 500 m respectively (see Riitters et al. 2002 for details). Fig. 4 in Appendix 4 illustrates how the size and distribution of the fragmentation classes change with the different analysis window sizes (3×3, 5×5, and 9×9 cells).

The percent changes in the forest areas that are classified into the least fragmented class (interior) and most fragmented (patch) was calculated to provide insights into the spatial pattern of the forest patches. For example, large percent decreases in interior areas or percent increases in patch areas as the analysis window size increases suggest that the forests are arranged in small patches or in patches with complex shapes and edges (see Fig. 4 in Appendix 4 for illustration of this line of logic). Percent change is defined as:

$$\frac{f2-f1}{f1}\times 100$$

where: f1 = area in the fragmentation category when using the immediately smaller analysis window size; f2 = area in the fragmentation category when using the immediately larger analysis window size.

Analysis of forests effective proximity to anthropogenic influences

Effective distance or proximity considers factors that facilitate or create difficulty to the movement of the phenomenon under study (in our case humans). Hence, it is not measured in units of distance, but in units of time, cost, or friction (see ArcGIS 9.3 Help Online).

The effective proximity of the forests to anthropogenic influences was calculated for 1993 (Series II) and 2002 (Series III) as follows. Anthropogenic land uses (Appendix 2), population centre locations, and main roads and highways were combined into a single layer representing the location of sources of anthropogenic influences. This layer was used as the source layer parameter in the ArcGIS 9.3 Cost Distance function to calculate effective distance. The second parameter for this function is a cost or friction raster. This raster defines the cost or friction to travel through each cell. Given the available information, slope and roads were considered the two factors that influence the friction to the movement of anthropogenic influences. The rasters for each of these factors were reclassified into friction values expressed in minutes as specified in Table 1, and then combined into a single raster. The minutes (min) assigned to each cell represent the time per unit distance (meter) for moving through the cell (the Cost Distance algorithm multiplies this value by the cell resolution, 100 m, and compensates for the diagonal movement to obtain the time of passing through a cell).

Given that the roads layer contains only paved main roads and highways, an average speed of 50 km per hour (h) was assigned to all cells representing roads. On-foot speeds vary with slope as presented in table 1. Several walking speed tests were conducted in each slope class to come up with these values. To be conservative on the distances that can be reached, the low end of the walking speed ranges observed in the tests were assigned to each slope range. These values are consistent with findings in other studies (Verburg et al. 2004).

**Table 1 On-road and off-road travel speeds (km/h) and friction values (min/h) assigned to each cell in the cost raster used in the ArcGIS Cost Distance function.**

| Type of travel | Transport type | Travel Speed (km/h) | Friction value assigned to each cell (min/m) |
|---|---|---|---|
| Off-road | | | |
| 0-5% slope | on-foot | 1.8 | 0.03333 |
| 5-10% slope | on-foot | 1.5 | 0.03999 |
| 10-20% slope | on-foot | 0.9 | 0.06666 |
| 20-50% slope | on-foot | 0.3 | 0.19999 |
| > 50% slope | on-foot | 0.06 | 60 |
| On-road | vehicle | 50 | 0.0012 |

The effective proximity to anthropogenic influences calculated for the Series III (reclassified into one-hour effective proximity classes) can be explored through the mapping website developed for this study (http://fast.ucdenver.edu/Mexico).

Derivation of an indicator of the degree of anthropogenic pressure on the remaining forests based on the location of deforested areas

With the information available, and based on reports in the literature that proximity to anthropogenic influences is related to

higher levels of deforestation (e.g. Chomitz & Gray 1996; Nepstad et al. 2001; Soares-Filho et al. 2001; Munroe et al. 2002; Verburg et al. 2004; Cayuela et al. 2006), we decided to use this spatial relationship to derivate an indicator of the degree of anthropogenic pressure on the remaining forests as follows. First, the location of the areas that have been deforested between 1993 (Series II) and 2002 (Series III) were identified using the ArcGIS 9.3 Erase function to compute the difference between the areas reported for each forest type in the Series II and those reported in the Series III. This approach results in an estimation of gross deforestation (i.e. it does not account for increases in the forest cover due to forest plantations or land cover transitions). For our purposes, the exact quantification of the deforested areas is not as important as the spatial relation of these areas to the effective proximity of the forests to anthropogenic influences. Second, the effective proximity (in minutes) to anthropogenic influences calculated for the forests in the Series II (1993) was reclassified into one-hour classes. Third, the deforested areas were cross referenced (using the ArcGIS 9.3 Tabulate Area function) with the effective proximity layer to obtain the percentage of the total deforested area that falls within each one-hour effective proximity class (see Table 3 in results section). These percentage values can be interpreted as indicators of the impact of the effective proximity to anthropogenic influences on deforestation, and hence constitute an estimate of the degree of anthropogenic pressure on the forests in a scale 1 to 100. One class was created for all effective proximity times above 10 h because beyond this threshold the percent of total deforested areas that fall within each subsequent effective proximity hour changes little and is less 1%.

The anthropogenic pressure values were assigned to the remaining forest areas as follows. The forest areas in the Series III (2002) that fall within each effective proximity to anthropogenic influences hour were obtained by cross tabulating (using the ArcGIS 9.3 Tabulate Area function) the forests reported in the Series III with their effective proximity to anthropogenic influences calculated also for this date. It is safe to say that the factors that influenced deforestation in the 1993-2002 period remain the same nationwide after 2002 (e.g. Alix-Garcia et. al. 2004; Works & Hadley 2004). Hence, the anthropogenic pressure in a scale 1-100 calculated as explained before can be assigned to the one-hour effective proximity to anthropogenic influences classes now calculated for the remaining forests reported in the Series III (2002). These pressure values can be interpreted as the likelihood of deforestation occurring in the remaining forest areas that fall within each effective proximity hour.

Finally, in contrast with traditional printed maps, we decided to deliver the study results through the World Wide Web and Google Earth™. This approach allows the dynamic exploration of the information at multiple scales. The rich contextual information, recent satellite images, and spatial visualization features available through Google Earth™ allow end users to develop their own visual analyses without the need for local high-end computing and software technology. We developed a web mapping application (http://fast.ucdenver.edu/Mexico) programmed in HTML and JavaScript that automatically starts Google Earth™ (GE) in the end user's computer and then responds to requests for maps of our results. The end user must have GE locally installed in his computer (it can be downloaded from http://www.google.com/earth/download/ge/agree.html). Our layer of population centres with their names is displayed once the user zooms in beyond an "eye altitude" of 35 miles (reported in the lower right hand side in the Google Earth™ version 5.2.1 interface). For display purposes in GE we only show the population centres with more than 100 inhabitants that exist inside and up to five miles beyond the edge of the forest areas reported in the Series III. The towns layer serves well as location reference points when exploring remote forest areas at multiple scales in GE.

## Results

Fragmentation maps of all forest types

The fragmentation classes maps created through the Riitters *et al.* (2000) method for each forest type corresponding to the 9x9 cell analysis window size can be explored in the mapping website developed for this study (http://fast.ucdenver.edu/Mexico). Fig. 3 shows an example of the fragmentation classes and anthropogenic pressure map results.

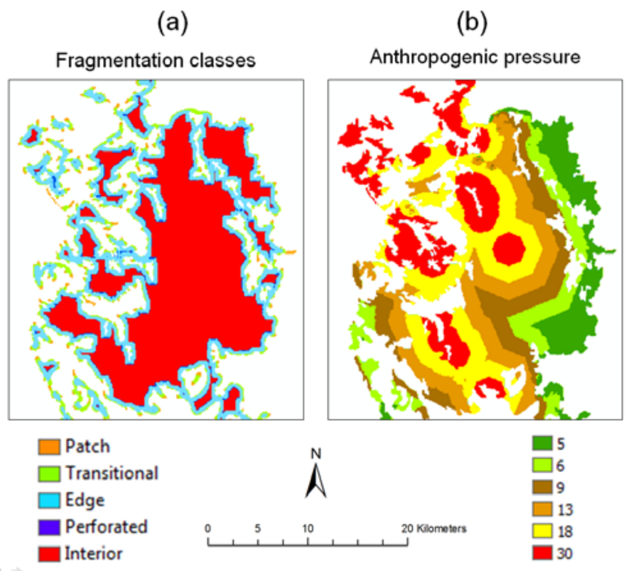


**Fig. 3 Example of forest fragmentation classes in a coniferous forest (a) and level of anthropogenic pressure on the same forest area (b).**

Table 2 contains the results of the fragmentation analysis for each forest type and analysis window size. The values are the area in hectares classified into each fragmentation class and the percentage of the total forest type area that these hectares represent. Also, it shows the percent changes in the areas classified in the most and least fragmented class (patch and interior) as the analysis window size increases from 3×3, to 5×5, and 9×9 cells (see columns in italics).

**Table 2 Fragmentation results using the Riitters et al. (2000) model for all forest types in Mexico.**

| Forest type | Fragmentation categories area (ha) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Patch | % | % change by window size (1) | Transitional | % | Edge | % | Perforated | % | Interior | % | % change by window size (1) |
| Coniferous forest | | | | | | | | | | | | |
| 3x3 Window | 8,693 | 0.05 | | 363,295 | 2.16 | 411,292 | 2.45 | 1,158,384 | 6.90 | 14,839,329 | 88.43 | |
| 5x5 Window | 44,762 | 0.27 | 414.92 | 526,363 | 3.14 | 2,462,789 | 14.68 | 621,233 | 3.70 | 13,125,846 | 78.22 | -11.55 |
| 9x9 Window | 229,088 | 1.37 | 411.79 | 1,081,253 | 6.44 | 4,491,546 | 26.77 | 429,433 | 2.56 | 10,549,673 | 62.87 | -19.63 |
| Broadleaf forest | | | | | | | | | | | | |
| 3x3 Window | 12,564 | 0.07 | | 544,136 | 3.13 | 609,483 | 3.51 | 1,681,641 | 9.68 | 14,525,617 | 83.61 | |
| 5x5 Window | 69,675 | 0.40 | 454.56 | 798,350 | 4.60 | 3,565,870 | 20.52 | 876,502 | 5.05 | 12,063,044 | 69.43 | -16.95 |
| 9x9 Window | 367,239 | 2.11 | 427.07 | 1,673,234 | 9.63 | 6,181,553 | 35.58 | 541,583 | 3.12 | 8,609,832 | 49.56 | -28.63 |
| Tropical dry decidious forest | | | | | | | | | | | | |
| 3x3 Window | 13,882 | 0.07 | | 500,434 | 2.37 | 597,903 | 2.83 | 1,578,665 | 7.48 | 18,406,603 | 87.25 | |
| 5x5 Window | 62,406 | 0.30 | 349.55 | 719,735 | 3.41 | 3,439,617 | 16.30 | 866,994 | 4.11 | 16,008,735 | 75.88 | -13.03 |
| 9x9 Window | 296,144 | 1.40 | 374.54 | 1,505,080 | 7.13 | 6,308,112 | 29.90 | 603,108 | 2.86 | 12,385,043 | 58.70 | -22.64 |
| Tropical sub-evergreen rain forest | | | | | | | | | | | | |
| 3x3 Window | 2,891 | 0.04 | | 88,733 | 1.27 | 115,158 | 1.64 | 282,146 | 4.03 | 6,512,797 | 93.02 | |
| 5x5 Window | 12,776 | 0.18 | 341.92 | 127,170 | 1.82 | 627,602 | 8.96 | 156,795 | 2.24 | 6,077,382 | 86.80 | -6.69 |
| 9x9 Window | 53,618 | 0.77 | 319.68 | 266,584 | 3.81 | 1,175,013 | 16.78 | 114,291 | 1.63 | 5,392,219 | 77.01 | -11.27 |
| Tropical evergreen rain forest | | | | | | | | | | | | |
| 3x3 Window | 1,482 | 0.04 | | 77,701 | 2.23 | 87,054 | 2.50 | 232,912 | 6.68 | 3,089,154 | 88.56 | |
| 5x5 Window | 8,381 | 0.24 | 465.52 | 113,961 | 3.27 | 507,060 | 14.54 | 121,033 | 3.47 | 2,737,868 | 78.49 | -11.37 |
| 9x9 Window | 47,807 | 1.37 | 470.42 | 242,324 | 6.95 | 894,201 | 25.63 | 77,316 | 2.22 | 2,226,655 | 63.83 | -18.67 |

In Table 2 in can be observed that the broadleaf forests have the smallest percentage of their total area classified as interior of all the forest types at every analysis window size (83% at 3×3, 69% at 5×5, and 49% at 9×9), followed by the tropical dry deciduous forests (87%, 75% and 58% respectively). Also, these forests have the largest proportion of their total area classified into the fragmented categories (patch and transitional) of all the forest types at every window size. According to Riitters et al. (2000) minor changes in the amount of forests in the transitional category can dramatically affect the number of forest patches, the size of the largest forest patch, and landscape-scale connectivity.

When analyzing the percent changes information (columns in italics in Table 2), the broadleaf forests have the largest percent decreases in interior areas of all the forest types studied as the analysis window size increase ( -16.9% from 3×3 to 5×5, and -28.6% from 5×5 to 9×9), followed by the tropical dry deciduous forests (-13% and -22.6% respectively). The tropical evergreen forests have the largest percent increases in the areas that become classified as patch as the analysis window size increases followed by the broadleaf forests and the tropical dry deciduous forests. These results suggest that these forest types are arranged in small patches or in patches with complex shapes and edges (see methods and Fig. 4 in Appendix 4 for illustration of this line of logic).

In contrast to the results for the previously mentioned forest types, the tropical sub-evergreen forests and coniferous forests have the largest percent of their total areas classified as interior and the smallest areas classified as patch or transitional of all the forest types studied at every analysis window size. Also, these forest types have the smallest percent change increases in the hectares that become classified as patch as the analysis window increases. These results suggest that the areas of these forest types are arranged in more compact forest patches with simpler shapes.

Effective proximity and degree of anthropogenic pressure on the remaining forests

Table 3 presents the gross deforested areas 1993-2002 that are found within each effective proximity hour to anthropogenic influences calculated for the Series II (1993). As explained in the methods section these values were later used to derive values of anthropogenic pressure on the remaining forests reported in the Series III from 2002.

Of the total deforested areas (18,118,970 ha), almost half (48.4%) have occurred within the first effective proximity hour to anthropogenic influences, and almost 75% within the first three effective proximity hours (see totals per proximity hour in table 3). Only 15% of the deforestation has occurred in areas beyond five effective proximity hours from anthropogenic influences.

**Table 3. Gross deforested areas 1993-2002 (in ha) that are found within each effective proximity hour to anthropogenic influences calculated for the forests in the Series II (1993).**

| Effective Proximity Hour | 1 (ha) | % of total | 2 (ha) | % of total | 3 (ha) | % of total | 4 (ha) | % of total | 5 (ha) | % of total | 6 (ha) | % of total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Coniferous forest* | 1,788,692 | 29.5 | 1,056,406 | 17.4 | 749,673 | 12.4 | 528,269 | 8.7 | 358,580 | 5.9 | 246,504 | 4.1 |
| *Broadleaf forest* | 1,116,305 | 34.1 | 608,134 | 18.6 | 402,125 | 12.3 | 278,989 | 8.5 | 184,671 | 5.6 | 123,401 | 3.8 |
| *Tropical dry decidious forest* | 3,641,310 | 66.8 | 840,929 | 15.4 | 352,344 | 6.5 | 178,777 | 3.3 | 98,078 | 1.8 | 60,924 | 1.1 |
| *Tropical sub-evergreen forest* | 1,079,383 | 59.9 | 263,691 | 14.6 | 109,663 | 6.1 | 66,758 | 3.7 | 47,702 | 2.6 | 34,445 | 1.9 |
| *Tropical ever-green forest* | 1,148,253 | 75 | 196,378 | 12.8 | 67,621 | 4.4 | 25,791 | 1.7 | 12,131 | 0.8 | 6,589 | 0.4 |
| **Total deforested area by proximity hour** | 8,773,943 | | 2,965,538 | | 1,681,426 | | 1,078,584 | | 701,162 | | 471,863 | |
| **Percent of total deforest area** | 48.40% | | 16.40% | | 9.30% | | 6.00% | | 3.90% | | 2.60% | |

| Effective Proximity Hour | 7 (ha) | % of total | 8 (ha) | % of total | 9 (ha) | % of total | 10 (ha) | % of total | >10 (ha) | % of total | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Coniferous forest* | 180,363 | 3 | 135,724 | 2.2 | 104,933 | 1.7 | 81,474 | 1.3 | 834,795 | 13.8 | 6,065,413 |
| *Broadleaf forest* | 81,892 | 2.5 | 57,697 | 1.8 | 39,424 | 1.2 | 28,843 | 0.9 | 349,293 | 10.7 | 3,270,774 |
| *Tropical dry decidious forest* | 38,247 | 0.7 | 22,857 | 0.4 | 13,798 | 0.3 | 8,971 | 0.2 | 192,315 | 3.5 | 5,448,550 |
| *Tropical sub-evergreen forest* | 29,443 | 1.6 | 25,975 | 1.4 | 24,040 | 1.3 | 20,359 | 1.1 | 100,962 | 5.6 | 1,802,421 |
| *Tropical ever-green forest* | 4,626 | 0.3 | 3,653 | 0.2 | 3,035 | 0.2 | 2,581 | 0.2 | 61,154 | 4 | 1,531,812 |
| **Total deforested area by proximity hour** | 334,571 | | 245,906 | | 185,230 | | 142,228 | | 1,538,519 | | 18,118,970 |
| **Percent of total deforest area** | 1.80% | | 1.40% | | 1.00% | | 0.80% | | 8.50% | | |

There is a remarkable difference in the percentage of total deforested area that occurs in close effective proximity to anthropogenic influences between temperate forests and tropical forests (see percentage columns in Table 3). In the first effective proximity hour, the percent of total deforestation (and hence level of anthropogenic pressure) that occurs in tropical forests is on the average twice as much as the one that occurs in temperate forests (e.g. tropical evergreen forest 75% vs. coniferous forest 30%). On the other hand, the percentage of total deforestation that occurs farther from anthropogenic influences decreases more sharply in tropical forests than in temperate forests (e.g. tropical evergreen forests 75% in first hour,13% in second, 4% in third, 2% in fourth, and less than 1% in fifth hour; versus 30%, 17%, 12%, 9%, and 6% in coniferous forests). These results suggest that in tropical forests anthropogenic pressures are much higher in the immediate vicinity to anthropogenic activities and decrease more rapidly with effective distance than in temperate forests. These results are congruent with findings in other studies of the tropical forests in Mexico that report higher deforestation rates in areas closer to anthropogenic land uses (e.g. Dirzo & Garcia 1992; Trejo & Dirzo 2000; Burgos & Maass 2004).

Table 4 shows the proportion of the total area of each forest type reported in the Series III that falls within each one-hour effective proximity to anthropogenic influences. Also, it shows the estimated level of anthropogenic pressure on the remaining forests for each forest type and one-hour effective proximity class. Notice how, as explained in the methods section, the percent of total deforested area columns in italics in table 3 become anthropogenic pressure values in Table 4.

The tropical forests have a larger proportion of their total areas within one hour effective proximity to anthropogenic influences than the temperate forests (47% vs. 23%; see totals rows in table 4). Only 12% of the total tropical forest areas are beyond five effective hours from anthropogenic influences compared with 29% in the case of the temperate forests. These results indicate that the tropical forests are more accessible to anthropogenic influences and that there is less area that can be considered far from these influences than in the temperate forests.

Looking at the specific forest types results in Table 4, the tropical dry deciduous forests have the largest proportion of their total area within one effective proximity hour to anthropogenic influences (49%) and are subjected to one of the highest anthropogenic pressures (67 in a scale 0-100). Only 11% of their total area (smallest percentage of all forests studied) is more than five effective proximity hours away from anthropogenic influences. These results support the findings in studies that have identified this forest type as under the greatest threats of degradation and in need of urgent conservation actions (e.g. Trejo & Dirzo 2000).

The layers called "Anthropogenic Pressure" for each forest type can be explored using the mapping web application developed for this study (http://fast.ucdenver.edu/Mexico). To facilitate the visualization of the information in these layers, all effective proximity times above five hours were grouped into a single category. Beyond five effective proximity hours the anthropogenic pressure values change little and the total forest areas are small.

**Table 4. Series III (2002) total forest area (ha) and associated anthropogenic pressure corresponding to each one-hour effective proximity to anthropogenic influences class calculated for the year 2002.**

| Effective proximity hour | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | >10 | Totals (ha) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Coniferous forests*** | | | | | | | | | | | | |
| *Anthropogenic pressure* | *29.5* | *17.4* | *12.4* | *8.7* | *5.9* | *4.1* | *3.0* | *2.2* | *1.7* | *1.3* | | |
| Area in each proximity hour (ha) | 4,119,681 | 3,252,328 | 2,341,162 | 1,637,883 | 1,129,337 | 788,314 | 549,433 | 386,577 | 279,994 | 196,249 | 2,097,405 | 16,778,363 |
| Percent of total area | 24.6% | 19.4% | 14.0% | 9.8% | 6.7% | 4.7% | 3.3% | 2.3% | 1.7% | 1.2% | 12.5% | |
| ***Broadleaf forests*** | | | | | | | | | | | | |
| *Anthropogenic pressure* | *34.1* | *18.6* | *12.3* | *8.5* | *5.6* | *3.8* | *2.5* | *1.8* | *1.2* | *0.9* | | |
| Area in each proximity hour (ha) | 3,700,097 | 2,987,628 | 2,304,730 | 1,704,092 | 1,237,776 | 909,614 | 679,213 | 506,952 | 380,178 | 281,053 | 2,679,880 | 17,371,213 |
| Percent of total area | 21.3% | 17.2% | 13.3% | 9.8% | 7.1% | 5.2% | 3.9% | 2.9% | 2.2% | 1.6% | 15.4% | |
| ***Tropical dry decidious forests*** | | | | | | | | | | | | |
| *Anthropogenic pressure* | *66.8* | *15.4* | *6.5* | *3.3* | *1.8* | *1.1* | *0.7* | *0.7* | *0.4* | *0.3* | | |
| Area in each proximity hour (ha) | 10,362,316 | 4,370,988 | 2,151,799 | 1,177,285 | 686,800 | 421,000 | 265,310 | 168,247 | 107,125 | 73,774 | 1,279,935 | 21,064,579 |
| Percent of total area | 49.2% | 20.8% | 10.2% | 5.6% | 3.3% | 2.0% | 1.3% | 0.8% | 0.5% | 0.4% | 6.1% | |
| ***Tropical sub-evergreen forests*** | | | | | | | | | | | | |
| *Anthropogenic pressure* | *59.9* | *14.6* | *6.1* | *3.7* | *2.6* | *1.9* | *1.6* | *1.4* | *1.3* | *1.1* | | |
| Area in each proximity hour (ha) | 2,910,273 | 1,485,444 | 829,989 | 489,972 | 307,749 | 213,151 | 144,650 | 105,974 | 85,265 | 69,122 | 318,648 | 6,960,237 |
| Percent of total area | 41.8% | 21.3% | 11.9% | 7.0% | 4.4% | 3.1% | 2.1% | 1.5% | 1.2% | 1.0% | 4.6% | |
| ***Tropical evergreen forests*** | | | | | | | | | | | | |
| *Anthropogenic pressure* | *75.0* | *12.8* | *4.4* | *1.7* | *0.8* | *0.4* | *0.3* | *0.2* | *0.2* | *0.2* | | |
| Area in each proximity hour (ha) | 1,528,972 | 593,369 | 323,738 | 196,668 | 134,488 | 103,165 | 79,920 | 61,674 | 51,803 | 40,245 | 372,252 | 3,486,294 |
| Percent of total area | 43.9% | 17.0% | 9.3% | 5.6% | 3.9% | 3.0% | 2.3% | 1.8% | 1.5% | 1.2% | 10.7% | |
| **Totals** | | | | | | | | | | | | |
| Total Temperate Forest area by hour (ha) | 7,819,778 | 6,239,956 | 4,645,892 | 3,341,975 | 2,367,113 | 1,697,928 | 1,228,646 | 893,529 | 660,172 | 477,302 | 4,777,285 | 34,149,576 |
| Percent of Temperate Forests by hour | 22.9% | 18.3% | 13.6% | 9.8% | 6.9% | 5.0% | 3.6% | 2.6% | 1.9% | 1.4% | 14.0% | |
| Total Tropical Forest area by hour (ha) | 14,801,561 | 6,449,801 | 3,305,526 | 1,863,925 | 1,129,037 | 737,316 | 489,880 | 335,895 | 244,193 | 183,141 | 1,970,835 | 31,511,110 |
| Percent of Tropical Forests by hour | 47.0% | 20.5% | 10.5% | 5.9% | 3.6% | 2.3% | 1.6% | 1.1% | 0.8% | 0.6% | 6.3% | |
| Total forest area by hour (ha) | 22,621,339 | 12,689,757 | 7,951,418 | 5,205,900 | 3,496,150 | 2,435,244 | 1,718,526 | 1,229,424 | 904,365 | 660,443 | 6,748,120 | 65,660,686 |
| Percent of total forest area by hour | 34.5% | 19.3% | 12.1% | 7.9% | 5.3% | 3.7% | 2.6% | 1.9% | 1.4% | 1.0% | 10.3% | |

## Discussion

The fragmentation method used in this study (Riitters et al. 2000) offers two important features: First, the maps of fragmentation classes allow the analysis of the areal distribution and spatial interactions of fragmentation information with other natural and anthropogenic features and processes. Second, by varying the analysis window and cell sizes used in this method different fragmentation scenarios can be created (e.g. Riitters et al. 2002). These features are major advantages given the existing uncertainty and diversity of effects of forest fragmentation on specific ecosystems, species, and ecological processes.

The combination of our results of forest fragmentation, effective proximity to anthropogenic influences and estimates of anthropogenic pressure on the remaining forests can assist in changing how monitoring, management, conservation, restoration, and economic incentives efforts are conceived and prioritized in Mexico. For example, fragmented areas in close effective proximity to anthropogenic influences with high associated anthropogenic pressures can be targeted to reduce their vulnerability through education, management actions and economic incentives. Recently, the need to identify this type of areas in Mexico to improve the impact of payments for forest ecosystem services on the conservation of these ecosystems has been highlighted (Muñoz-Piña et al. 2008). Another example, numerous and large reforestation efforts have been carried out in Mexico with very limited success (Saenz-Romero 2003). These efforts often have concentrated on areas in close effective proximity to anthropogenic influences with high associated anthropogenic pressures. In these areas socio-cultural, economic, institutional-legislative, and environmental conditions are not likely to allow the long-term support of forests in the near future. Parallel to these reforestation efforts, resources could be channeled to perforated, edge, and transitional fragmentation class areas with medium or low anthropogenic pressure identified in this study. In these areas forests still remain and investments can help to expand forest patch core areas and slow down or reversed degradation processes.

Fig. 3 illustrates the previous points. Fig. 3a shows the fragmentation classes for a coniferous forest in northwest Mexico. The large interior area of the forest patch in the centre of the figure could give the impression of high suitability for wildlife habitat or conservation purposes. However, the effective proximity to anthropogenic influences and associate anthropogenic pressure information shown in fig. 3b for the same forest patch can change this initial perception. A community found in the middle of the large forest patch creates high anthropogenic pressure in the area. The small forest patches on the top left of the figure are subjected to high anthropogenic pressures due to their

effective proximity to anthropogenic land uses; management actions to reduce their vulnerability to degradation might be appropriate in these areas. In contrast, the forest areas on the right of the figure have low estimated anthropogenic pressures. The interior areas of these forest areas might be more suitable for wildlife habitat or conservation purposes.

The broadleaf forests high fragmentation indicators must be considered in the context that most of these forests are embedded or adjacent to coniferous forests. Also, they have a large proportion of their areas far from anthropogenic influences with relatively low associated levels of anthropogenic pressure. Hence, the threats for their conservation are not as high as for other types of forests.

Of more concern for conservation and management purposes are the high values of fragmentation found for the tropical evergreen forests which are scarce and are subjected to high anthropogenic pressures. Also of concern are the tropical dry deciduous forests, although these forests are comparatively abundant, they have high indicators of fragmentation and are subjected to the highest levels of anthropogenic pressure found in this study. The fragmentation could be in part natural to this type of vegetation, but also it has been attributed to extensive anthropogenic disturbances (Trejo & Dirzo 2000). Our results are congruent with studies that put these types of forests among the most threatened ecosystems in Mexico and the world (Dirzo & Garcia 1992; Trejo & Dirzo 2000; Burgos & Mass 2004; Galicia et al. 2008; Román-Cuesta et al. 2006; Portillo-Quintero & Sanchez-Azofeifa 2009).

Our estimate of total deforested area during 1993 to 2002 (18,118,970 ha; see Table 3) is higher than estimates reported in recent national land cover change reports (e.g. Mas et al. 2004; Velazquez et al. 2005). This is due first, to the methodology we used which estimates gross forest cover change; and second, to differences in the definitions of the forest covers studied. The difference we found in the relation of deforestation rates to the effective distance from anthropogenic influences in tropical and temperate forests are congruent with reports from previous studies in the tropical forests in Mexico (Dirzo & Garcia 1992; Trejo & Dirzo 2000; Burgos & Mass 2004). Anthropogenic impacts tend to be greater in the immediate vicinity of anthropogenic activities in these forests in part due to their vegetation density and location in steep topography (particularly evergreen tropical forests) which complicate humans movement in these forests.

Our study does not distinguish between natural and anthropogenic fragmentation. For some ecosystem functions or species this distinction does not matter. However, we recognize that knowing the causes of fragmentation in different places is essential for developing effective monitoring, management, conservation, and restoration plans. Also, the following issues must be considered when interpreting the results of this study: First, the data sets errors, uncertainty, and scale (1:250,000) with its associated generalization effects (see Joao 1998); and second, the effects on the results of the interaction of cell size and scale (see Turner et al. 1989; O'Neill et al. 1996; Greenberg et al. 2001; Riitters et al. 2002; Garcia-Gigorro & Saura 2005; Corry & Lafortezza 2007). Nevertheless, the tens-of-thousands of hectares level is appropriate to interpret our results and sufficient to identify trends at the national level and to support strategic level decision at the national level.

The absence of information on the location of dirt roads in the forests is important for the impacts they have on fragmentation and ecosystem functions (Forman & Alexander 1998; Spellerberg 1998; Trombulak & Frissell 2000; Ouren et al. 2007). Unfortunately, this information at the national level for Mexico is not likely to be available in the short run. In our study the following factors provide some alleviation for this absence. Towns and small communities in the forests are found along dirt roads, our population centres data includes even very small communities (with less than 100 inhabitants); associated with these communities there are land uses we identified as anthropogenic (explore the Google Earth images where you can see the dirt roads in combination with our fragmentation results and population centres layer at http://fast.ucdenver.edu/Mexico). These two data sets were used as sources of anthropogenic influences and provide a proxy for the location of the dirt roads in the forests.

## Conclusions

The fragmentation characteristics, proximity to anthropogenic influences, and estimated level of anthropogenic pressure indicate that the tropical forests in Mexico are under greater pressures than the temperate forests. It is necessary to accelerate efforts to enhance the monitoring, management and conservation knowledge of tropical forests which generally lags behind the temperate forests. More specifically, when considering jointly all the information generated in this study, the tropical evergreen forests and tropical dry deciduous forests are under the greatest pressure and threat of degradation processes.

The information generated in this study can assist in enhancing the design and prioritization of monitoring, management, conservation, restoration, and economic incentives strategies for the forest in Mexico. The maps of forest fragmentation, effective distance to anthropogenic influences and levels of anthropogenic pressure on the forests can be spatially cross referenced with other natural and socio-economic factors and process to improve the understanding of their interactions and behaviors in space and time. Our estimates of effective distance to anthropogenic influences and levels of anthropogenic pressure on the forests are only likely to be revised upward as more information becomes available and new factors are incorporated into our analyses.

This study should be considered as a first approximation to a spatially explicit estimation of the forest fragmentation, forest effective proximity to anthropogenic influences, and levels of anthropogenic pressure on the remaining forest areas at the national level in Mexico. Future studies can develop on our results by: Incorporating the information on dirt roads in the forests as soon as it becomes available; adding layers of socio-economic and cultural factors (e.g. land tenure, poverty, level of community forestry activity) to the analyses here presented; incorporating population potential or gravity models to the estimation of effective proximity to anthropogenic influences (e.g. Verburg *et*

*al.* 2004); exploring the effects of cell size and multiple scales on forest fragmentation estimates (e.g. Riitters *et al.* 2002; Garcia-Gigorro & Saura 2005; Wickham *et al.* 2007); and distinguishing better natural patterns versus anthropogenic-driven patterns of forest fragmentation because their effects and future consequences are not the same. We are already carrying out work on several of these enhancements.

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**Appendix 1:** Vegetation types included in the definition of each forest type.

**INEGI's Series II (1993)**
The vegetation community information contained in the "Comunidad" attribute field was used to define the following forest types:

| Forest type | "Comunidad" |
|---|---|
| Coniferous forests | 'Bosque de tascate'<br>'Bosque de oyamel (incluye ayarin y cedro)'<br>'Bosque de pino'<br>'Bosque de pino-encino (incluye encino-pino)' |
| Broadleaf forests | 'Bosque bajo-abierto'<br>'Bosque de encino'<br>'Bosque mesofilo de montana' |
| Tropical dry deciduous forests | 'Selva mediana caducifolia y subcaducifolia'<br>'Selva baja caducifolia y subcaducifolia'<br>'Selva baja espinosa' |
| Tropical sub-evergreen forests | 'Selva alta y mediana subperennifolia'<br>'Selva baja subperennifolia' |
| Tropical evergreen forests | 'Selva alta y mediana perennifolia'<br>'Selva baja perennifolia' |

**INEGI's Series III (2002)**
The vegetation type information contained in the "TIP_VEG" attribute field was used to define the following forest types:

| Forest type | "TIP_VEG" |
|---|---|
| Coniferous forests | 'BOSQUE DE TASCATE'<br>'BOSQUE DE CEDRO'<br>'BOSQUE DE AYARIN'<br>'BOSQUE DE OYAMEL'<br>'BOSQUE DE PINO'<br>'MATORRAL DE CONIFERAS'<br>'BOSQUE DE PINO-ENCINO' |
| Broadleaf forests | 'BOSQUE DE ENCINO'<br>'BOSQUE MESOFILO DE MONTANA'<br>'BOSQUE DE ENCINO-PINO' |
| Tropical dry deciduous forests | 'SELVA MEDIANA SUBCADUCIFOLIA'<br>'SELVA MEDIANA CADUCIFOLIA'<br>'SELVA BAJA SUBCADUCIFOLIA'<br>'SELVA BAJA CADUCIFOLIA'<br>'SELVA BAJA ESPINOSA CADUCIFOLIA' |
| Tropical sub-evergreen forests | 'SELVA ALTA SUBPERENNIFOLIA'<br>'SELVA MEDIANA SUBPERENNIFOLIA'<br>'SELVA BAJA SUBPERENNIFOLIA'<br>'SELVA BAJA ESPINOSA SUBPERENNIFOLIA' |
| Tropical evergreen forests | 'SELVA ALTA PERENNIFOLIA'<br>'SELVA MEDIANA PERENNIFOLIA'<br>'SELVA BAJA PERENNIFOLIA' |



**Appendix 2:** Land covers included in the definition of anthropogenic land uses

**INEGI's Series II (1993)**
The land cover information contained in the "Comunidad" attribute field was used to identify the following land uses as anthropogenic:

| "Comunidad" | Translation |
|---|---|
| 'Agricultura de humedad' | Residual humidity agriculture |
| 'Agricultura de riego (incluye riego eventual)' | Irrigation agriculture (including sporadic irrigation) |
| 'Agricultura de temporal' | Rainfed agriculture |
| 'Asentamiento humano' | Human settlement |
| 'Plantación forestal' | Forest plantation |
| 'Pastizal cultivado' | Cultivated grassland |

**INEGI's Series III (2002)**
The land cover information contained in the "CLAVEFOT" attribute field was used to identify the following land uses as anthropogenic:

| "CLAVEFOT" | Translation |
|---|---|
| ZU Zona Urbana | Urban zone |
| AH Asentamientos Humanos | Human settlements |
| PI Pastizal Inducido | Induced grassland |
| VP Palmar inducido | Induced palm groves |
| IAPF Agricola-Pecuaria-Forestal | Agriculture-Livestock-Forestry |

**Appendix 3:** Justification for choosing the Riitters *et al.* (2000) fragmentation method.

This method was chosen over other alternatives for the following reasons. It generates maps of fragmentation classes allowing the analysis of the areal distribution and spatial interactions of fragmentation information with other natural and anthropogenic phenomena and processes. For management, conservation, and stakeholder outreach purposes, it is more useful to have maps displaying the spatial distribution of the fragmentation information. The principles and calculations used to assign a fragmentation class to each cell are conceptually intuitive and computationally simple. This facilitates the understanding and relation of the method's results to stakeholders' local knowledge and experiences on the ground. Finally, the model is easily implemented through the use of the ATtILA (http://epa.gov/esd/land-sci/attila/index.htm) extension for the Geographic Information System (GIS) ArcView 3.x (ESRI, Redlands CA).

**Appendix 4:** Justification for choice of 100 ×100 m cell size.

This cell size was chosen because: it allows the detailed representation of the forest patch shapes; most conservation and management decision are taken at the hectare level (100 x 100 m); and it allows the creation of scenarios (by varying the analysis window size) of plausible influence or levels of penetration of

edge effects of diverse natural and anthropogenic processes into the forest patches. Finally, it has been shown that edge effects have their greatest influences within 100 m of the forest edge (Laurance & Yensen 1991, Laurance et al. 1998 and 2002).

Fig. 4 illustrates how the size and distribution of the fragmentation classes change with the different analysis window sizes (3×3, 5×5, and 9×9 cells). For example, notice how the interior areas are reduced and become less connected as the analysis window size increases. At the same time, cells closer to the edges, or arranged in narrow peninsulas, are increasingly classified into the fragmented categories (edge, transitional, and patch) as the analysis window size increases.

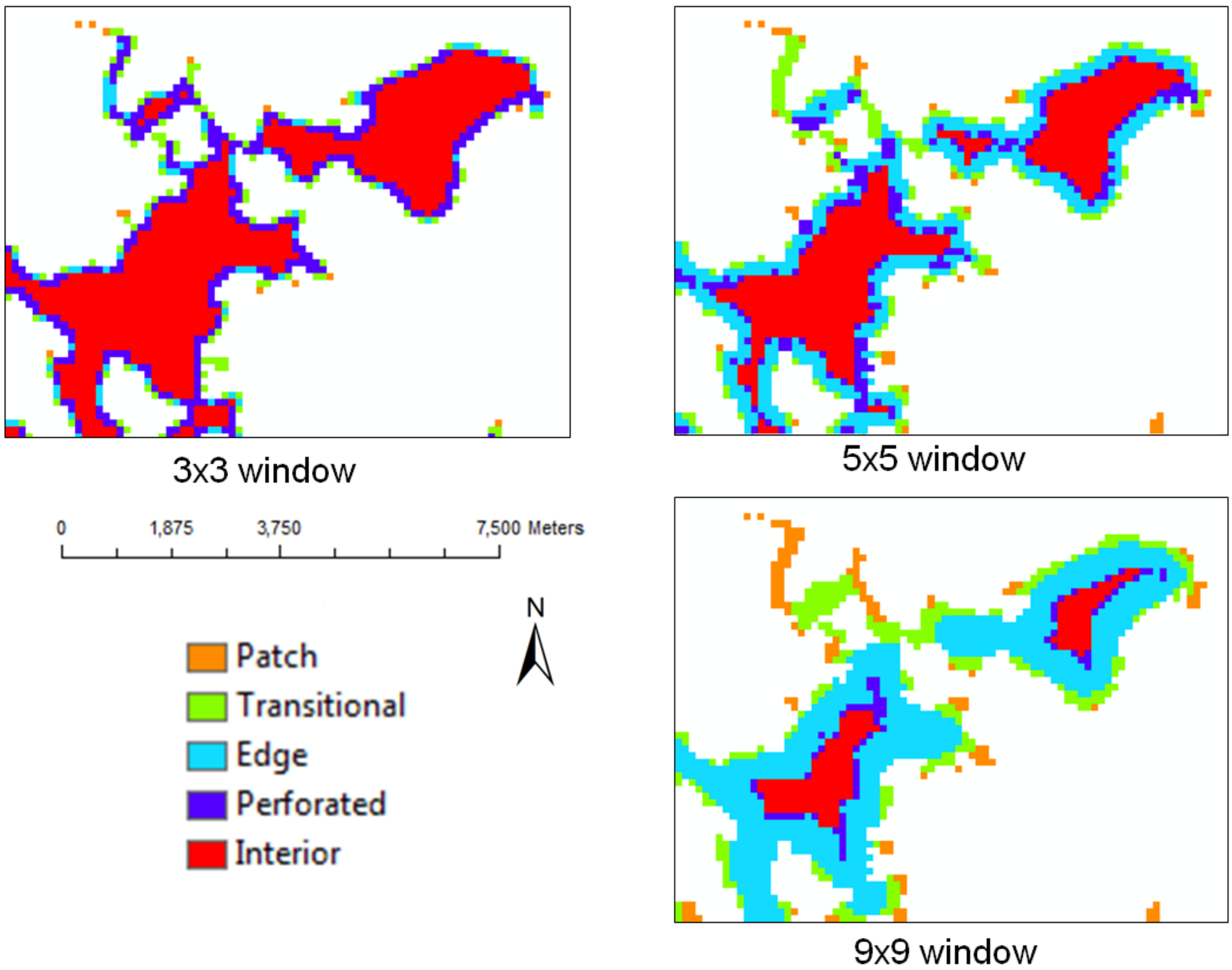


**Fig. 4 Example of the distribution of fragmentation classes with changing analysis window size.**